POWER SHARING CONDITIONING CONTROL IN SINGLE-PHASE PARALLEL DISTRIBUTED GENERATIONS WITH SIMPLE IMPROVEMENT OF DROOP CONTROL

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To my beloved family: Mom, Dad, Brother, Sister and Fiancé

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ABSTRACT

Droop control is the critical solution for sharing the power demand between Distributed Generations (DGs) in islanding microgrid when there is no support from the electricity distribution grid. The droop control is applied as the local control scheme to achieve power sharing among parallel inverters with DG sources. As it has been well established, this control strategy is combined frequency and voltage droop method. In droop strategy, the voltage and frequency are drooped to a new rated value to ensure power load sharing. Therefore this project to have an improvement of the droop under self-frequency restoration method is adopted in order to obtain accurate power sharing and fast frequency tracking capability with better load sharing between parallel DGs are been conducted in this project. It is where the improved droop control is used to have faster restoration for the voltage and frequency to nominal values within a limited time and to ensure the proper power sharing between the DGs considering based on the rating of energy source. The performance of the proposed controller is implemented in MATLAB/Simulink software and compared by two simulation tests under two exigent load circumstances as well also as through the connection of DGs to the point of common coupling (PCC). It is to verify the proposed control model has capability to response accurately during the power transient and power sharing conditions at both DGs. In proportion, the implementation of frequency restoration loop to the improved droop control has create a condition where it knows as an autonomous smart grid system whereby the restoration of the frequency and voltage can be done automatically. As a result, the improved controller can achieve better steady-state performance and fast restoration tracking speed within 3.5ms with 2.8ms rise time as compared to 8.5ms rise time for the conventional droop control. It also reduces the overshoot during the load transient to 4% and increases the tracking efficiency by 90% as compared to the 40% overshoot and 85% efficiency for the conventional control. Hence, the autonomous smart microgrid system is successfully

presented under this proposed controller along with accurate power sharing performance between DGs and fast frequency restoration.

ABSTRAK

Kawalan susut adalah merupakan penyelesaian utama untuk perkongsian kuasa di antara penjana pengagihan (PP) di dalam grid tersendiri yang berskala kecil di mana ia tidak memerlukan sokongan daripada grid utama pengagih elektrik. Kawalan susut digunakan sebagai skim kawalan tempatan untuk menyediakan perkongsian kuasa di antara penyongsang selari berlandaskan sumber PP. Seperti yang telah ditubuhkan, kawalan ini beroperasi dengan menggabungkan amplitud dan frekuensi voltan. Dalam kawalan susut, amplitud dan frekuensi voltan akan susut ke nilai baru agar memastikan perkongsian beban kuasa berlaku. Oleh itu, penambahbaikan kawalan susut dibawah kaedah pemulihan frekuensi kendiri telah diadaptasi untuk perkongsian kuasa yang lebih tepat dan keupayaan mengesan frekuensi agar memastikan pengkongsian beban yang lebih baik di antara PP selari telah dilaksanakan dalam projek ini. Pada peringkat ini kawalan susut yang lebih baik digunakan untuk pemulihan yang lebih pantas untuk voltan dan frekuensi kepada nilai sebenar dalam masa yang terhad untuk memastikan perkongsian kuasa yang tepat berdasarkan sumber tenaga. Prestasi kawalan susut ini dilaksana menggunakan perisian platform MATLAB/Simulink dan diuji melalui dua kajian simulasi iaitu di bawah perubahan dua beban utama dan melalui sambungan PP ke titik gandingan bersama (TGB). Ini bertujuan untuk mengesahkan model kawalan yang dicadangkan mempunyai keupayaan untuk bertindak secara tepat semasa berlaku perubahan kuasa di antara PP. Secara amnya, sistem pintar terjadi apabila pemulihan voltan dan frekuensi dilaksanakan secara automatik dengan adanya laluan pemulihan frekuensi dalam penambahbaikan kawalan susut. Natijahnya, kawalan yang lebih baik dapat mencapai prestasi yang terbaik dengan kelajuan pengesanan pemulihan dalam masa 3.5ms dengan 2.8ms masa kenaikan apabila dibandingkan 8.5ms untuk kawalan konvensional. Ia juga mengurangkan jumlah lebihan sebanyak 4% dan meningkatkan kecekapan pengesanan sebanyak 90% berbanding 40% jumlah lebihan dan 85% kecekapan untuk kawalan konvensional. Justeru, sistem automatik mikrogrid pintar

berjaya dibentangkan di bawah prestasi kawalan dengan memaparkan perkongsian kuasa yang tepat dengan pemulihan frekuensi yang cepat.

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LIST OF SYMBOLS AND ABBREVIATIONS

DG	-	Distributed generation
W	-	Watt
VAR	-	Voltage active reactive
kW	-	kilowatt
MW	-	Megawatt
AC	-	Alternating current
DC	-	Direct current
Δ	-	Delta
A	-	Current
V	-	Voltage
V_{dc}	-	Input voltage
V_o	-	Nominal output voltage
V_{mg}	-	Microgrid output voltage
E^*	-	Set-point voltage
I	-	Inverter output current
I_o	-	Nominal output current
Hz	-	Frequency
f_n	-	Nominal frequency
f_s	-	Switching frequency
f^*	-	Set-point frequency
f_g	-	Gird frequency
ω	-	Omega (2*π*f)
θ	-	Voltage phase (°)
P	-	Active power
P_L	-	Load active power
P_i	-	Inverter active power

ΔP	-	Active power deviation
Q	-	Reactive power
Q_L	-	Load reactive power
Q_i	-	Inverter reactive power
ΔQ	-	Reactive power deviation
m	-	Frequency droop coefficient (rad/W.s)
n	-	Voltage droop coefficient (V/VAR)
K_p	-	Proportional gain
K_i	-	Integral gain
s	-	second

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CHAPTER 1

INTRODUCTION

1.1 Project background

In recent years, the renewable energy sector is becoming more interesting for being research due to its penetration into the integrated microgrid system. It is also due to the decarbonisation policy [1] that has been set by the United Nation to reduce global warming, which has become a turning point for renewable energy in generating more clean energy in the future. The interconnection of small generation systems such as solar photovoltaic panels, fuel cells and energy storage devices to low-voltage distribution network has also led to congestion on the dynamic power system. These power sources give rise to the capability of decentralised generation, known as distributed generations (DGs) [2]. Nowadays, the advancements in designs and component materials related to DG have increased the range of applications and opportunities for advanced DG configuration with higher controller response. These advanced technologies together with the restructuring of wholesale and retail markets for electric power have also opened the possibility for an energy system that gives more freedom for customers to manage their power in order to meet their own needs [2], [3].

A microgrid is defined as a system that has at least one DG as well as energy storage devices and associated loads connected at the common bus bar network. A microgrid can operate in two different modes of operation: interconnected mode, where it is connected to the main upstream grid from which power is being supplied or to which it injects power, and in an autonomous way of operation, which is disconnected from the distribution network. In grid-connected mode, each DG in the microgrid does not have to regulate the voltage of the system as this is done by the stiffer main grid [4]–[6]. Meanwhile, in autonomous mode, DGs are responsible and required for regulating the voltage and frequency of the microgrid and for supplying power to meet the local load's requirement with acceptable power quality without jeopardising the entire network. The application of this particular electrical power system is appropriate for supplying power in rural areas, where power demand is relatively low and where it is not cost-effective to install transmission lines and provide power from the main grid [7], [8]. This concept is becoming more important due to the increase of renewable energy power penetration in order to reduce the reliance on conventional power generations.

The fundamental control objective of DGs in a microgrid is to achieve accurate power sharing while regulating the microgrid's voltage amplitude and frequency in order to become autonomous. A centralised control strategy based on communication architecture has been proposed in [9], [10]. However, it is impractical and costly to be used with communication links in remote areas due to the long distances between inverters. Therefore, decentralised controllers are investigated to eliminate communication links [11], [12], and they have become an option nowadays. This is because the power sharing for microgrid generators is achieved using droop controller strategy, which is based on synchronous generator operation to balance frequency and voltage when the real and reactive power demand changes [13]. Droop control can be enhanced by featuring the transient response performance by means that depends on active power (P) and reactive power (Q) [14]. To decrease the P and Q dependency, droop control with virtual output impedance [15] and a secondary virtual frequency-voltage frame [16] are also discussed. Although these control methods can improve the overall power sharing factors, they have complexities in adjusting the control parameters.

Therefore, this research takes the initiative to propose an improved droop control technique for droop-based parallel-connected inverters associated with the local load by using local adjustments to adjust the output of the inverter voltage amplitude and frequency to ensure accurate power sharing to be delivered to the local loads with fast frequency restoration tracking. It should provide a robust performance against all conditions mentioned. In the meantime, the proposed controller will be tested at two DG inverters connected to three loads at a typical bus bar during the transient mode between the loads. Thereby, the droop control method will allow the DGs to be able to share the total power load demand by adjusting inverter output voltage frequency and amplitude as a function of the desired P and Q.

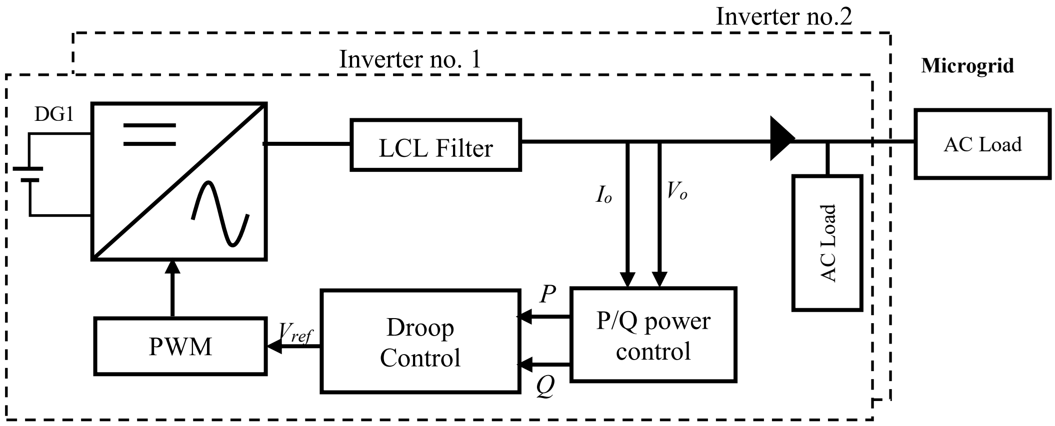

Figure 1.1: Conventional parallel DGs system design coordinated with droop control method

The conventional system associated with a legitimate control strategy is shown in Figure 1.1. As shown, the system consists of external P/Q power control coordinated with the droop control strategy. The proposed system will be put together in a parallel configuration in bus-connected to simulate an autonomous microgrid. An improved droop will generate a new sine wave reference signal ($V_{droop\_generator}$) for gate pulse switching (PWM). The controller performance is tested thoroughly with several cases to verify the controller response.

1.2 Problem statement

In the case where two DGs are connected at the same bus bar, the power sharing situation should be properly investigated and studied. This is because when each inverter has a different power, the output of the inverter voltage amplitude and frequency is at an unstable state. However, there is an inherent trade-off between load sharing accuracy and voltage amplitude and frequency regulation. In the conventional droop control design process, the power sharing can happen when an accurate droop coefficient is selected. In choosing this droop gain coefficient, where it is based on the boundary limit of the voltage and frequency, an inherent trade-off occurs [17]. This is because the proportion to droop characteristic upon coordination between active-frequency (P-f) and reactive power-voltage (Q-V) needs to be established to maintain system stability. Good power sharing can also be conceived by adjusting the output voltage amplitude and frequency of the inverter. To have shared power among the inverters, the voltage amplitude and frequency droop coefficient should be at a range of accepted value. Without a legitimate control strategy, the adjustment of these values might disrupt the power sharing performance and interrupt voltage output as well. However, there are few resources in terms of investigations on droop coefficient of more than one number coefficient [18]. Additionally, in the existing droop controller, the frequency of an autonomous microgrid continuously changes according to the variation of load demand and the restoration process is executed in a more prolonged period [19]. This is because of the slow transient response. As is well known, if the frequency deviation suddenly rises due to load changes that will cause the system frequency to deviate more than 50 Hz, it will create a power outage to the system.

Therefore, it is vital to have an accurate droop controller combined with high-speed frequency tracking to generate a precise power sharing while maintaining the voltage output. Consequently, it will make the voltage amplitude and frequency of the reference voltage signal to follow the droop as the load current increases, and these droops are used to allow independent inverters to share the load in proportion to their capacities. It also allows both active and reactive powers to be controlled indirectly and in autonomous mode in order to achieve fast voltage-frequency restoration tracking with better steady-state performance.

1.3 Research objective

The objectives of this research are as follows:

1. To develop an improved power conditioning control based on droop control strategy for accurate power sharing for both inverters at the point of common connection.
2. To design a minimum time for frequency tracking response for an autonomous smart grid.
3. To compare the improved droop control strategy with the conventional method in local microgrid power sharing conditions.

1.4 The scope of the study

The scopes of the project are broken into several categories involving the simulation and performance testing:

1. The droop control strategy for the single-phase inverter microgrid network is designed in MATLAB/Simulink platform software.
2. The design concept is based on the stand-alone inverter with voltage and current from the inverter output side, which are used as control feedback.
3. The inverter used is based on universal bridge inverter block obtain from Simulink library.
4. The system is tested with different reference voltages of $120V_{rms}$ and $230V_{rms}$, with 50Hz frequency.
5. The DG input is applied with a constant input value where DG1 and DG2 have values of $120V_{rms}$ and $230V_{rms}$, respectively. All the DC sources are assumed to have a stable regulated output.
6. The controller design is being limited based on the coordination between voltage/frequency (V/f) droop characteristics.
7. The microgrid design is based on a small-scale microgrid associated with the local load in purely inductive line.
8. The highlighted parameters being observed on the controller response towards DG operation are response time, tracking speed and steady-state settling period.

1.5 Thesis organisation

This thesis comprises five chapters. A detailed explanation is discussed respectively for every section as follow:

Chapter 1: Project introduction is presented in this section, followed by the research problem and objectives to solve the faced problem. The scopes of the research project also are constructed at the end of the chapter.

Chapter 2: A comprehensive literature review regarding power conditioning control extracted based on droop control strategies is presented in detail from previous research. In this section, the selection of a suitable power controller approach for inverter-based microgrid is considered. The summarisation and the tabulated data of selected and relevant control strategies are compared in terms of advantages, disadvantages, reliability and robustness of controller performance.

Chapter 3: This chapter presents the methodology of the whole study to achieve the objectives. The flow of the proposed power controller based on voltage and frequency droop control strategies is also discussed further in this chapter. All the relevant modelling parameters are also illustrated.

Chapter 4: The results and discussion are provided in this chapter. The simulations of the proposed power controller are tested to ensure its validity. To demonstrate the accuracy, the power sharing performance of the load has been set accordingly. The comparison between the existing power controller and the proposed approach is also discussed deeper in this chapter.

Chapter 5: This conclusion of the research are summarised in the final chapter. The recommendation for future research also has been listed in this section.

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